COMMISSIONING AND OPERATION OF THE CDF SILICON DETECTOR

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The CDF-II silicon detector has been partially commissioned and used for taking preliminary physics data. This paper is a report on commissioning and initial operations of the $5.8m^2$ silicon detector. This experience can be useful to the large silicon systems that are presently under construction.

Introduction

The collider detector at Fermilab (CDF) is designed to study proton-antiproton collisions at a centre of mass energy of 1.98 TeV. The experimental apparatus had a major upgrade recently, in order to take advantage of the upgraded luminosity of the Tevatron accelerator. A general description of the apparatus can be found elsewhere in there proceedings [1,2] and in the Technical Design Report [3]. The Silicon Detector is a high-precision microstrip tracker that covers the pseudorapidity region $|\eta| < 2$, with an outer radius of 28 cm and a coverage of $|z| < 50$ cm along the beam axis, around the nominal interaction point. The detector consists of 3 subsystems: "L00" is the innermost, single-sided strip layer at 1.35 cm from the beam line; "SVX" is a 5-layer, double-sided silicon microstrip tracker, made of 3 identical barrels placed along z, each with a 12-fold geometry in the polar angle ϕ; "ISL" is the outer part [4], consisting of one-layer, double-sided central barrel and two double-layer barrels, also with double-sided silicon microstrips, in the forward and backward regions. The three subsystems use the same front-end chip [5,6], the same control cards [7] and the same readout system [8]. They differ in the sensor geometry, the read-out hybrids and power supplies.

The total area of the double-sided silicon is $5.8m^2$, and features 722500 strips read out by 5644 front-end chips.

The chip is the heart of the Silicon Detector. It consists of a charge amplifier, a double correlated sample and hold circuit, an analog pipeline, a comparator and ADC and threshold logic for sparsification of 128 strips. The analog pipeline is 42 cells deep and works at 7 MHz. The chip allows for Dynamical Common mode noise rejection (DCMNR) and dead-time-less

operation. Each chip is programmable with a 197 bit word to set bandwidth, signal polarity, DCMNR, threshold, calibration mask.

The interconnection system includes 1.75 million wire bonds to single strips, 310 thousand wire bonds to chips, 10 thousand wire bonds to control lines and 816 connections to receiver/transmitter circuits that control more than one module (5 modules for SVX, 10 for ISL).

Given the size of the detector and its flexibility in terms of parameters to set, the commissioning was a formidable task.

1   Commissioning

The Silicon Detector was extensively tested at the fabrication facility throughout the construction process. Each part had passed tests with very stringent parameters e.g. less than 2% of disconnected channels, no readout errors [9]. Functional tests were made at each step. All ladders had passed the tests before insertion in the barrel, but after barrel assembly 11 modules out of 360 have developed anomalously high noise on single channels or clusters of channels. We believe this problem is due to buildup of surface charge on the interface with the oxide layer. In fact it affects only a small fraction of detectors and only in layer-2 and layer-4. These are small-angle stereo detectors, their fabrication structure is different from that of the remaining layers and they come from a different manufacturer.

The detector was repeatedly tested during assembly and before shipment to the experimental hall, which is located a few kilometers away from the fabrication facility. The system grounding was always reasonably good and, provided that all the ground straps of the ladders were connected to the bulkhead, the noise performance was, for the majority of the devices, the same as measured on single devices before assembly.

We could not test the Silicon Detector in the assembly hall because the electronics and power supply crates are mounted on the walls of the collision hall, while the cables had been installed on the main CDF detector. So the complete chain of readout, power supply and controls had to be tested all at the same time when the detector was rolled in.

We initially cabled only a part of the detector consisting of 50 ladders. We finished the cabling during a one month shutdown of the accelerator. We tested parts of detectors as long as they were cabled. The cables, the power supplies and the data acquisition components had been previously tested separately with one standard test stand and had passed the specification requirements. We repeated a detailed test of each component when it was in place in the collision hall. The power supplies and their cables were first tested

with a resistive load and voltages, currents, protection circuits and interlocks were checked. Then functional tests of the DAQ-related part were performed making use of a portable test device, that we called "wedge in a box". It consists of 5 SVX hybrids and one portcard, with solid-state cooling. This device was known to read-out correctly within a defined range of conditions so that functional test and debugging was performed on the DAQ and on its cables. This method was also essential to identify 3 low voltage cable bundles that had passed the passive load test but had a dispersion on the ground connection, due to mechanical damage.

Once the "outer" part of the system was fully debugged, the real detector segment was connected to it and completely tested.

The cabling and testing operation was long in time and required a large effort for a variety of reasons: the space available for the cable connections, at the end of the tracking volume and the clearance for plugging the cables were extremely limited; the failure rate of component that were previously was higher than expected.

It required a large, organized effort by 30 people. The main operating difficulty was due to the tuning of the interlock system that protects the system and was being commissioned at the same time. It had to allow the system to be powered under non normal conditions, especially high humidity, and keep the detector safe. A false alarm on the temperature was, initially, difficult to recognize and could block the cabling crew for several hours, inhibiting any power to the detector.

Cables are assembled in bundles consisting of one voltage cable, one sense, one command, one bias voltage cable and 5 optical cables. A small number of cables had to be replaced: 4 voltage cables, 3 voltage sense cables, 6 data (optical) cables, 3 command cables out of 114 bundles. Also 3 FIBs (Fiber Interface Board) had to be replaced. The largest difficulty was due to the optical link between the front-end (portcard) and the Read-out (Optical Fiber Transition Module). The high failure rate was due to the light level mismatch between transmitter and receiver. A 9-channel optical cable is driven by a custom-made monolithic DOIM GaAs laser [10]. Five transmitters, (45 channels) share the same power voltage. They have been selected to have about the same characteristics, but the same was not done for the receivers. Some difference in light level produced a considerable error rate. In addition some receiver modules had flaky pin connections to the VME board. Re-insertion after contact cleaning was necessary for a large number of receivers.

Another source of difficulty was due to the power supplies [11]: 35 out of 102 developed problems and had to be repaired. We had not received the PS modules in time for detector commissioning and were only able to operate a

partial system. We have commissioned and operated 70% of SVX and 35% of ISL. The L00 is only partially commissioned due to the late arrival of power supplies and also to wait for stable operation of the Tevatron beam.

The ISL had a cooling blockage problem [2], but the totality of the detector has been functionally tested, but only for a very short period to avoid overheating.

The overall result of this test was that 3 SVX wedges could not be readout. For one of them the problem has been identified in a short between two signals inside the detector. This was not present before shipment. As a lesson learned, at level of system design, we should have allowed the use of standard protections for vital wire bond connections, at the cost of a more difficult procedure for test and re-work. Also minimizing the transport of the sealed detector, if at all possible, would be desirable. Two other wedges are being investigated during access in October 2001. 9 wedges could not be powered due to lack of tested power supplies, 48 ladders had readout problems related to optical power mismatch and could not be operated.

2 Integration

After test in the collision hall, the ladders were re-tested one by one with a stand-alone version of the DAQ program, checking for readout errors under "standard" conditions. Ladders that passed this test were integrated in the CDF DAQ. The difficulties that we had in this phase were due to communication errors to the Power Supplies that gave rise to spontaneous turning on and off of apparently random channels. This was solved by improving the timing of this communication, by decreasing the number of power supplies served by the same serial line and with software checks. In particular the PS Users Interface program was changed to add a number of tests that made it considerably slower than foreseen.

On the DAQ front, as the light output of the DOIMS depends on their operating temperature, we had new cases of mismatch due to the increased light power when operating at -6^oC.

We had to develop tools to synchronize the power supply to the daq system and to constantly monitor the operation in order to respond efficiently to any error message. The number of ladders integrated vs. time is shown in fig. 1 (a). The steady linear increase was due to the testing procedure, that had to negotiate time with "physics" data taking of the rest of CDF, so that we could operate the detector only in a fraction of time. In addition, we required the Silicon to be in off status during beam injection and unstable beam conditions. The availability of DAQ time was the main factor limiting
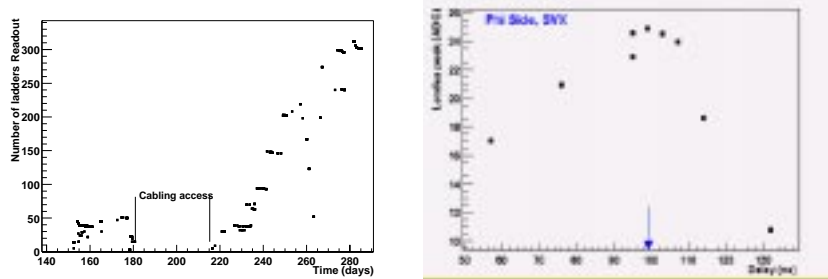
Figure 1. (a) Number of Silicon modules integrated with CDF vs. time. (b) Timing scan: pulse height vs. relative phase of the chip clock with respect to the beam crossing.

a rapid increase of the number of integrated ladders. The setback around day 260 was due to a VME power supply failure and momentary inability to operate a part of the system.

3 Operations

We have collected to date 4.5 pb^{-1} of physics quality data on tape; this excludes detector studies and special runs to check the trigger rate.

In order to operate the Silicon in the most stable way we decided to make full use of the chip capability and operate it in DCMNR-on mode. A fixed threshold of 5 ADC counts, about 16% of the most probable m.i.p. signal, gave a reasonable readout time, and occupancy completely acceptable at the present low trigger rate. We have not optimized the chip parameters yet, although we are already using the best compromise between having a uniform standard set of parameters and good performances. The first variable to set in the Silicon system was the timing, i.e. the relative phase between the bunch crossing and the issue of L1 trigger to the chip. Failing to syncronize correctly would result in a loss of charge and "spillage" of charge in the neighbouring beam crossing packets. Before plug-in we have measured the delay of all command cables. They were all the same, within 2 ns. Using the the data from the first beam collisions we did a coarse and fine time scan, as shown in fig. 1 (b), and verified that all the detectors show a maximum at the same delay, as expected.

The noise performance with and without beam are as expected and we are not experiencing any measurable pick-up from the beam or from the outer part of the detector. Some ladders have a 50% increased noise in those chan-

nels located above the support rails. This sensitivity to the infrastructure is probably due to loosened ground connections and the problem is being addressed during access. Otherwise the noise is the same as measured at the fabrication facility.

Measuring the pedestal and noise is essential to operate correctly the detector. Two calibration methods have been implemented. Firstly, in "Data-mode", data are collected with free running trigger in read-all mode. Then noise and pedestals are calculated off-line and the parameters written to the calibration database. This method is intrinsically slow, because the calibration constants are available a few hours after the run is finished. Especially in the initial commissioning phase, when detector parameters and configuration were changing continuously, we experienced difficulties in monitoring the data quality due to the time delay between data taking and calibration data ready. The "X-mode" calibration will allow for a fast turnaround. All
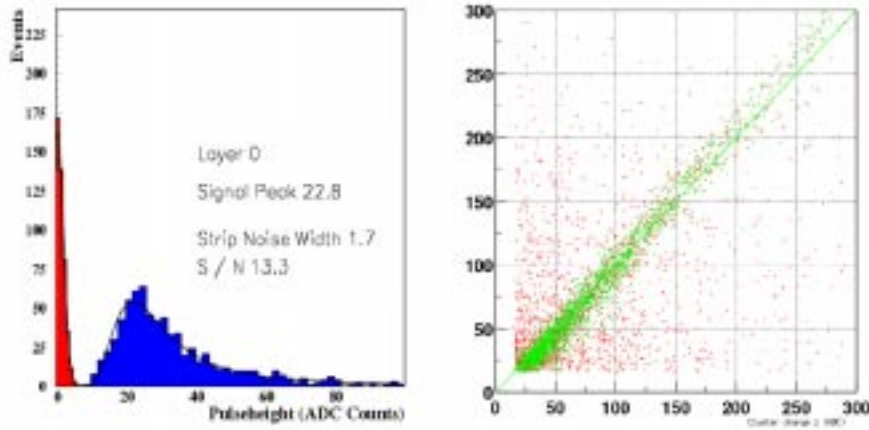

Figure 2. (a) Signal to noise for clusters on tracks, as measured with one ladder that was read in *read-all mode*.
(b)Correlation between the cluster charge on z side and cluster charge measured on the ϕ side, for all clusters. No tracking is applied. The gain of the amplifiers are well equalized.

the calculations of pedestal and noise are performed by the VME cpu in the collision hall. The final result is then loaded in the database in a matter of minutes. The FIB module can also subtract on-line any residual pedestal, so that data will be ready for clustering and for taking part to the second level trigger (SVT) [12].
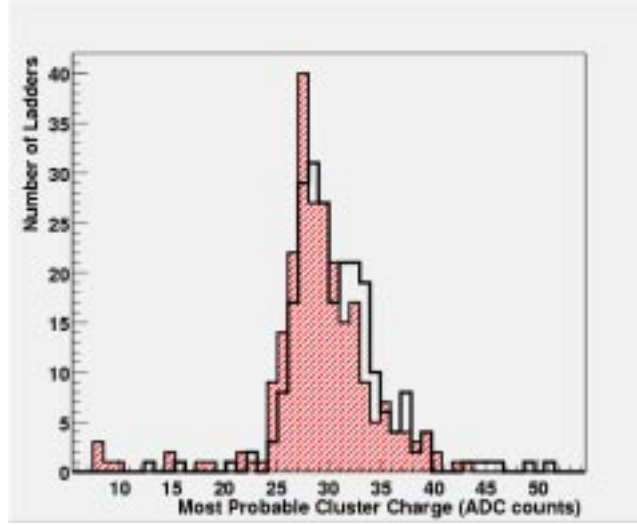
Figure 3. Distribution of the peak of the Landau distributions. There is an entry in this plot for each ladder that was read-out. The dashed histogram refers to the ϕ-side. The gain equalization was applied to the small-angle-stereo layers. Entries with low charge correspond to ladders that were not biased, while entries with high charge are due to histograms with low tracking statistics.

The on-line data monitoring is performed on-line by analyzing a percentage of the data with off-line code. Cluster charge for all clusters and for those belonging to a track are monitored, as well as occupancy and track parameters. Off-line data quality is monitored with larger statistics and makes use of the correct calibration constants. The cluster charge on tracks and the shape of the Landau distributions, corrected for the path length in Silicon, are checked both visually and with an automatic set of tests. These include a Kolmogorov test on the Landau distribution, with respect to a reference histogram, as a powerful automated test that flags which ladders to look at. Other useful variables are the ratio between the number of clusters on tracks and the total number of clusters, the ratio between the number of clusters on ϕ-side and the number of clusters on z-side. An example of pulse height distribution from SVX is shown in fig. 2-(a). The S/N was measured to be 13.3 and is in good agreement with the design value (11 to 17) [3], even before optimization of chip parameters. By changing these it is possible to equalize the gain, between ϕ and z-side, as shown in fig. 2 (b), where the charge cor-

relation between p and n side is shown. The distribution of peak position of the Landau distributions is shown in fig. 3, that is an overview of the detector pulse height performance. After the end of access we shall optimize the chip parameters to maximize the performances of the detector, but also important is that the detector configuration will be stabilized, in order to extract physics signals with constant efficiency.

We have already used the part of Silicon that we have commissioned to reduce the background in the J/ψ dimuon mass peak: in fig. 4 the distribution with silicon in is compared with the one obtained using only the information from the central tracking chamber and from the muon central chambers: the width is only 20% better, but the S/N improved by a factor of 2.5. The Silicon information has also been used in the second level tracking trigger [12].
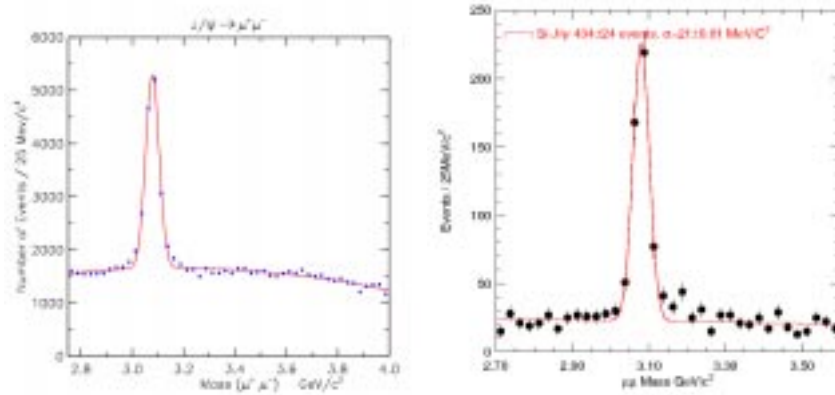

Figure 4. The J/ψ peak as measured requiring two muons in the central region. On the right it is shown the spectrum for the subset of events that have aat least one muon as a Silicon track.

Conclusions

The CDF Silicon Tracker is on its way to being fully commissioned. 70% and 35% of the SVX and ISL subsystems respectively have been taking data with beam collisions and have been used for extracting the first Physics signals. After an access to the detector that is occurring during this conference we plan to be able to run 97% of SVX wedges and recover as much ISL cooling

as possible. The detector will be fully operational for physics-quality data taking by January 2002.

Acknowledgments

References

1. J. Spalding, *Run-II upgrades and physics prospects*, these proceedings.
2. F. Palmonari [CDF Collaboration], *The CDF-II Silicon Tracking System*, these proceedings.
3. CDF Collaboration, *The CDF-II Detector Technical Design Report*, FERMILAB-Pub-96/390-E.
4. A. Affolder *et al.* [CDF Collaboration], *Intermediate Silicon Layers Detector For The Cdf Experiment*, *Nucl. Instrum. Methods* A **453**, 84 (2000).
5. M. Garcia-Sciveres *et al.*, *The SVX3d Integrated Circuit For Dead-Timeless Silicon Strip Readout*, *Nucl. Instrum. Methods* A **435**, 58 (1999).
6. T. Zimmerman *et al.*, *SVX3: A deadtimeless readout chip for silicon strip detectors*, *Nucl. Instrum. Methods* A **409**, 369 (1998).
7. J. Andersen *et al.* *The portcard for the Silicon Vertex Detector Upgrade of the Collider Detector at Fermilab IEEE Trans. Nucl. Sci.* **48**, 504 (2001).
8. M. Bishai [CDF Collaboration], *The CDF Silicon data acquisition system for Run-II*, these proceedings.
9. G. Bolla [CDF Collaboration], *Testing And Quality Insurance During The Construction Of The Svxii Silicon Detector Nucl. Instrum. Methods* A **473**, 53 (2001).
10. M. Chou et al.*Dense Optical Interface Module (DOIM)*Fermilab Internal document, Mar. 1996
11. Custom made power supplies A509, A510 and A509H for the SY527 crate system are made by CAEN.
12. I. Fiori [CDF Collaboration], *The CDF on-line silicon vertex trigger*, these proceedings.